COLD WATER REFUGE AT THE LOCKS

The Lake Washington Ship Canal
General Investigation Study

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1. Purpose and Background:

Currently the Locks create a very distinct separation of freshwater in the Ship Canal and saltwater in Puget Sounds. This distinct separation is believed to stress the fish as they move from the Puget Sound environment into the Ship Canal environment. In Puget Sound fish are in waters with a temperature of around 13^{o}C and dissolved oxygen levels around 7mg/L. As these fish pass through the Locks (via the fish ladder of the lock chambers) they are exposed to temperatures ranging from 21^{o}C – 13^{o}C and dissolved oxygen (DO) ranging from 9mg/L – 4mg/L. Even though there are temperatures and dissolved oxygen levels similar to that of Puget Sound within the Ship Canal, they do not occur simultaneously. In areas where there are cool water temperatures the dissolved oxygen levels are very low and in areas where there are high dissolved oxygen levels the water temperatures are extremely warm.

It is believed that by modifying the project operations (leaving the saltwater barrier down, operating the saltwater drain, spilling from the smolt slides and or performing more lockages) an estuary-like condition can be created for fish within the Ship Canal. This estuary-like condition would provide an area that would allow fish adapt to the changing environment slowly without stress. In July and August of 2000, a test was performed to determine if changing the operation of the Locks could affect the water quality in the Ship Canal.

The purpose of this test was to determine the following:

1. What is the area of impact?
2. How much can we change this area?
3. How long will this change last?

2. Method:

During this experiment 13 Hydrolabs and 1 YSI sensor were placed at 4 different locations around the Locks (see site location map). The sensor record dissolved oxygen, temperature, depth, salinity, and conductivity every 15 minutes. On August 9th, the sensors where cleaned and check. The following time intervals and operations were used during the study period.

Baseline Operation: July 24 – August 1

During this time the locks was operated under typical summer conditions.

No spill over the smolt slides.
No spill over the spillway.
Saltwater barrier up, except for deep draft vessels.
Normal fish ladder operations.
Saltwater drain was off (except for weekend nights 2100 – 0600 hour).

Saltwater Barrier Down: August 1 – August 5

Same as baseline except the saltwater barrier was left down.

Saltwater barrier left down.
No spill over the smolt slides.
No spill over the spillway.
Fish ladder flow where kept on (from saltwater drain and surface water).
Saltwater drain was off.

Saltwater drain On: August 5 - August 13

Same as baseline except the saltwater drain was operated from 0000 – 0600 hour and 1200–1800 hour everyday.

No spill over the smolt slides.
No spill over the spillway.
Saltwater barrier up, except for deep draft vessels.
Normal fish ladder operations.

Smolt Slide Spill: August 13 – August 18

Same as baseline except 90 cfs was put through the smolt slide 5C.

No spill over the spillway.
Saltwater barrier up, except for deep draft vessels.
Normal fish ladder operations.
Saltwater drain was off.

Increase Nighttime Lockages: August 19 – August 25

During this time the locks were operated under typical summer conditions except at night (0000-0600) when at least one eastbound lockage was performed every two. These periods were on August 19th, 21st, and 22nd.

No spill over the smolt slides.
No spill over the spillway.
Saltwater barrier up, except for deep draft vessels.
Normal fish ladder operations.
Saltwater drain was off.

Throughout the study period there were set times when there were no lockages performed. This was done to determine how the water temperature and dissolved oxygen levels reacted during periods of no lockages. These periods where from 0000 – 0400 on August 3, 8, 10, 13, 17, and 20.

3. Results:

<u>What is the area of impact?</u>

This discussion is focussed on the effect of operational changes at 2 locations: the bottom sensor at the large lock site and the bottom sensor at the wingwall site. These sensors have the greatest response to lockages and operational changes making the cause and effect easier to identify. Higher in the water column, at both the large lock site and wingwall site, the effects of lockages and operational changes are less obvious. See tables of results for the gradation within the water column.

There appears to be a transition layer for temperature, conductivity, and dissolved oxygen at about 6-8 meters from the surface. It is at this depth that there is some direct response to lockages but the duration of the effects is very short compared to deeper depths. At the large lock site, this depth can have characteristics like the fresh surface water or the bottom saltwater. During periods where there are high salinity inputs (saltwater barrier down), the 6-8 meters depth will appear more like the bottom saltwater and react more to lockages and operational changes. The bottom saltwater is characterized by having higher salinity, lower temperatures and lower dissolved oxygen. During periods of low salinity inputs (saltwater drain on), this depth becomes more freshwater-like and has little or no response to lockages or operational changes. The freshwater is characterized by having low/no salinity, high temperatures, and high dissolved oxygen levels.

At the wingwall, the 6 – 8 meter depth, can not be classified as having either freshwater or saltwater –like characteristics, however this depth is influenced by lockages and operational changes. The reason for this depth to react to lockages and operational changes near the wingwall site could be cause by the overall reduction of depth at this point and/or the affects of lockages and operational changes spreads out and affects a greater area.

At the large lock site and wingwall site the top 0-7 meters is not heavily influenced by lockages. Changes at these depths are mainly from the surface interface, diurnal fluctuations, biological components (algae) and water in the Ship Canal. Biological components, lockages, and lock operations are the primary influence below 7 meters (bottom at about 14 meters). As you move further from the Locks the effects caused by a single lockage or operational change are harder to evaluate. This is due to the dissolved oxygen, salinity, and temperatures become more homogenous with the ambient conditions. Based on historical salinity data within the Ship Canal, the area of impact in the water column is reduced as you move further from the Locks. This creates a wedge like affect.

How much can we affect this area?

This discussion is focussed on the effect of operational changes at 2 locations: the bottom sensor at the large lock site and the bottom sensor at the wingwall site. These sensors have the greatest response to lockages and operational changes making the cause and effect easier to identify. Higher in the water column, at both the large lock site and wingwall site, the effects of lockages and operational changes are less obvious. See the tables for the gradation within the water column.

Dissolved Oxygen Results:

Over the entire study period, dissolved oxygen at lower depths (below 6-8 meters) fluctuates more at the wingwall site than at the large lock site. The average rate at which the dissolved oxygen is reduced (by chemical/biological demands) is equal at both locations (-0.9mg/L per hour). At the wingwall the quantity of "new" water (from Puget Sound) is less than at the large locks. With less "new" water the dissolved oxygen levels tend to reach lower levels at the wingwall during periods of infrequent lockages then at the large locks. The minimum dissolved oxygen level at the large locks was 5.2mg/L and at the wingwall it was 3.6mg/L. At the large locks the average change per each lockages was 0.9mg/L and at the wingwall the average was 0.7mg/L.

Having the barrier down appeared to lower the average DO levels from 7.1mg/L to 6.9mg/L at the large locks and from 6.6mg/L to 6.1mg/L at the wingwall. This isn't what was expected. One explanation is that the with the barrier up it allows more opportunity for mixing of the high DO levels on the surface with the bottom layers. At both sites the minimum levels increased when the barrier was down and the maximum level decreased during this period. It appears that with the barrier down the DO levels do drop some but a more stable/consistent environment is created.

Operation of the saltwater drain reduced the average DO levels. At the lock site the average DO levels dropped from 6.9mg/L to 6.5mg/L and at the wingwall the levels dropped from 6.1mg/L to 5.6mg/L. It is believed that the saltwater drain removes the "new" saltwater water from the bottom and pulls water from the Ship Canal, which contains lower DO levels. This effect could increase as the duration at which the saltwater drain is on increases.

Operation of the smolt slide didn't have a significant effect on DO levels. Water that was removed from the surface, through the smolt slide, was replaced by similar water from the Ship Canal. With a longer duration of spill or a higher flows, one would be able to create a greater force to push the saltwater wedge closer to the locks. This results in warmer temperatures and higher DO levels at the bottom of the wingwall and cooler temperatures and lower DO levels at the bottom of the large lock site. This pushing back of the saltwater wedge with higher freshwater velocities is seen in naturally occurring estuaries as well. Increasing the flow through the Locks (over spillway, saltwater drain, smolt slides,) can push the saltwater wedge closer to the Locks.

During this study period lockages occurred on demand according to normal operations. On three evenings, lockages were performed every two hors from 0000 – 0600. On August 19th, dissolved oxygen levels stayed between 7.3mg/L and 6.7mg/L (averaging 6.9mg/L) at the large lock site. On August 21st, DO levels fluctuated from 7.5mg/L to 6.1mg/L (averaged 6.8mg/L), and on August 22nd, DO levels ranged from 6.9mg/L – 6.5mg/L with an average of 6.8mg/L. These evenings are above the minimum DO levels of 5.0mg/L and above the average DO levels of 6.2mg/L for this study period at the locks.

The dissolved oxygen levels, at the wingwall, on August 19th ranged from 6.8mg/L – 6.0mg/L and average 6.0mg/L. On August 21st the DO levels ranged from 5.3mg/L – 4.3mg/L and average 4.9mg/L and on August 22nd, dissolved oxygen levels fluctuated between 5.5mg/L and 4.6mg/L and averaged 5.1mg/L. These values were all above the minimum readings of 3.7mg/L, but below the average of 5.3mg/L (except the August 19th average) for this time period. Performing nighttime lockages should increase DO level both at the locks and at the wingwall. Because the test averages fell below the study period's average may mean that a more frequent lockage interval is required to overcome the biological and chemical oxygen at the wingwall. Determining whether performing additional lockings in the evenings can maintain a specific level of dissolved oxygen is very uncertain. It depends heavily on the existing levels in the Ship Canal, Puget Sound, and the desired levels. There is some ability to control dissolved oxygen levels with lockages but the exact frequency need depends on the current conditions.

Temperature Results:

This discussion is focussed on the effect of operational changes at 2 locations: the bottom sensor at the large lock site and the bottom sensor at the wingwall site. These sensors have the greatest response to lockages and operational changes making the cause and effect easier to identify. As you move up in the water column, at both the large lock site and wingwall site, the effects of lockages and operational changes are less obvious. See chart of results to see the gradation within the water column.

Temperature shows greater fluctuation at locks then at the wingwall. This is the exact opposite of DO, according to the over all averages from the entire study period. This is due to the water warming/mixing before it reaches the wingwall, so by the time the "new" water (from Puget Sound) reaches the wingwall it is closer to the ambient water temperature. At the large locks the maximum temperature was 21.9ºC and at the wingwall it was 22.3ºC. The minimum temperature at the locks was 13.0ºC and at the wingwall it was 15.6ºC. The large lock site fluctuated between 13.0ºC and 21.3ºC and had an average change of –1.2ºC after a lockage. The wingwall site fluctuated between 15.6ºC and 20.8ºC and had an average change of –0.9ºC.

With the barrier down the average temperature at the large locks decreased from 18.3ºC to 17.6ºC. At the wingwall the average temperature decreased from 18.4ºC to 17.7ºC during this study phase. With the barrier down it allows colder water from Puget Sound to enter ship canal.

When the saltwater drain was turned on the average temperature at the locks increased from 17.6ºC to 19.1ºC and at the wingwall it increased from 17.7ºC to 19.0ºC. The saltwater drain removes the cold water from the bottom and pulls in warmer water from the surface and from the isothermal Ship Canal.

During the spill phase of the average temperature at the locks decreased from 19.1ºC to 18.9ºC. This could be caused by the increased flow keeping more of the cold water closer to the locks. At the wingwall the average temperature increased to 19.2ºC. This to could be caused by the increased flow pushing more of the cold water to the locks allow more warmer water from the ship Canal to influence this area. This pushing back of the colder water with higher velocities is seen in naturally occurring estuaries as well. Increasing the flow through the Locks (over spillway, saltwater drain, smolt slides,) can push the colder water closer to the Locks.

At the locks the average temperature during nighttime lockage phase was 18.2ºC. There were three evenings (August 19th, 21st, and 22nd) where nighttime lockages occurred every 2 hours. The average evening temperature levels on August 19th was 18.0ºC, on the 21st it was 19.0ºC and on the 22nd it was 18.3ºC. Two out of the three evening events were above the study period's average of 18.6ºC.

During the periods where lockages occurred every two hours the averages at the wingwall were close to the study period average except for the August 21st. The average for the study period was 19.5ºC and on the 19th it was 19.3ºC, the 21st it was 19.8ºC and on the 22nd it was 19.3ºC. Determining if performing additional lockings in the evening can maintain a specific temperature is very uncertain. It depends heavily on the existing water temperature in the Ship Canal, the tide, and the desired temperature. Temperature can be controlled by lockages but the frequency needed depends on the current conditions.

<u>How long will it last?</u>

Looking at the amount of change caused by a lockage and rate at which the variable returns to equilibrium, one can determine the rate at which the effects of a lockage will last. For dissolved oxygen at the large lock site there is an average of 0.9mg/L increase with each lockage. The rate of decline is –0.2mg/L per hour. At these rates the effects of lockage on DO, at the locks, is about 4.5 hours. At the wingwall the affect of a lockage on DO is 0.7mg/L and the rate of decline is –0.2mg/L per hour making the affect time about 3.5 hours.

The average effect of a lockage on temperature at the locks was –1.2ºC and the rate at which the water warmed was 0.3ºC per hour resulting in an affect time of 4.0 hours. At the wingwall the amount of change by a lockage was –0.9ºC and the rate of warming was 0.2ºC per hour, resulting in an affect time of about 4.5 hours.

These are just averages and there are a lot of variables that can affect the amount of change and the rate of decline. These duration times are a very good estimate but things will need to be monitored and current conditions must be taken into account to insure the proper results.

4. Conclusion:

Lockages do have an affect on dissolved oxygen and temperature in the bottom 7 meters around the large locks and wingwall. Each time an eastbound lockage is performed it provides a pulse of cold water with higher dissolved oxygen levels. Depending on what the current conditions are in the Ship Canal, Lock operations and conditions in Puget Sound the affects can be fairly large (-1.8ºC and +1.3 mg/L for dissolved oxygen). It appears that performing an eastbound lockage every 4 hours should maintain existing DO and temperature levels at the locks. An evaluation of the current operations of the locks and the conditions in Puget Sound and the Ship Canal should be made to adjust this interval to obtain the desired results.

DISSOLVED OXYGEN (mg/L)

Locks

Condition	Depth	Min	Average	Max	Amount of Change	Rate of Change
Baseline	5.2 meters	7.6	8.0	8.4	0.0	0.0
	8.1 meters	7.2	7.7	8.1	0.0	0.0
	11.5 meters	6.8	7.2	7.7	0.3	0.0
	13.9 meters	5.7	7.1	7.6	1.0	0.1
	Mid Channel 14 meters	5.9	7.1	7.9	1.2	0.1
Barrier Down	5.2 meters	7.4	7.8	8.4	-0.1	0.0
	8.1 meters	7.1	7.5	8.0	0.1	0.0
	11.5 meters	6.4	6.9	7.4	0.1	0.1
	13.9 meters	6.4	6.8	7.3	0.2	0.1
	Mid Channel 14 meters	6.1	6.9	7.7	0.7	0.2
Drain On	5.2 meters	7.0	7.4	7.9	0.0	0.0
	8.1 meters	6.7	7.1	7.8	0.1	0.0
	11.5 meters	6.0	6.6	7.4	0.2	0.0
	13.9 meters	5.3	6.5	7.3	0.6	0.1
	Mid Channel 14 meters	5.2	6.5	7.6	0.9	0.2
Spill	5.2 meters	7.0	7.2	7.5	0.0	0.0
	8.1 meters	6.6	6.9	7.2	0.0	0.0
	11.5 meters	6.0	6.5	7.1	0.2	0.1
	13.9 meters	5.9	6.5	7.2	0.6	0.2
	Mid Channel 14 meters	5.6	6.5	7.5	0.8	0.2
Nighttime lockages	5.2 meters	6.7	7.1	8.9	0.0	0.0
	8.1 meters	6.4	6.8	8.8	0.0	0.0
	11.5 meters	5.5	6.2	8.4	0.3	0.1
	13.9 meters	5.0	6.2	9.0	0.6	0.1
	Mid Channel 14 meters	5.2	6.1	8.9	0.8	0.2

Wing wall

Condition	Depth	Min	Average	Max	Amount of Change	Rate of Change
Baseline	2.6 meters	7.6	8.1	8.5	0.0	0.0
	5.6 meters	7.2	7.6	7.9	0.1	#DIV/0!
	8.8 meters	7.0	7.4	8.0	0.2	0.0
	10.9 meters	6.3	6.9	7.6	0.1	0.1
	Mid Channel 14 meters	4.6	6.6	7.7	0.7	0.1
Barrier Down	2.6 meters	7.5	7.8	8.3	0.0	0.0
	5.6 meters	6.8	7.4	7.8	0.1	0.1
	8.8 meters	6.5	7.0	7.5	0.2	0.1
	10.9 meters	5.7	6.6	7.3	0.2	0.1
	Mid Channel 14 meters	5.0	6.1	7.2	0.5	0.2
Drain On	2.6 meters	6.5	7.2	7.9	0.0	0.0
	5.6 meters	6.7	7.0	7.5	0.1	0.1
	8.8 meters	6.0	6.8	7.6	0.3	0.1
	10.9 meters	5.3	6.3	7.3	0.2	0.1
	Mid Channel 14 meters	3.6	5.6	6.9	0.7	0.2
Spill	2.6 meters	6.9	7.2	7.7	-0.1	0.0
	5.6 meters	6.6	6.9	7.2	0.1	0.0
	8.8 meters	6.3	6.6	7.1	0.3	0.1
	10.9 meters	3.8	5.7	6.8	0.4	0.2
	Mid Channel 14 meters	4.4	5.8	6.7	0.4	0.1
Nighttime lockages	2.6 meters	5.9	6.7	7.6	0.0	0.0
	5.6 meters	6.1	6.6	7.1	0.1	#DIV/0!
	8.8 meters	5.6	6.6	6.9	0.2	0.1
	10.9 meters	3.3	4.4	5.9	0.8	0.2
	Mid Channel 14 meters	3.7	5.3	6.8	0.9	0.3

Gray areas where unable to be calculated. DO levels where to equal at these levels to determine an affect. Temerature change didn't produce reliable results to make a conclusion.

Temperature (C)

	Locks						Wing wall					
	Depth	Min	Average	Max	Amount of Change	Rate of Change	Depth	Min	Average	Max	Amount of Change	Rate of Change
Baseline	5.2 meters	20.6	20.8	21.2	0.0	0.0	2.6 meters	20.5	20.9	21.6	0.0	0.0
	8.1 meters	20.0	20.7	21.0	-0.1	0.0	5.6 meters	20.6	20.8	21.0	0.0	0.0
	11.5 meters	17.1	19.8	20.9	-0.5	0.1	8.8 meters	19.8	20.5	20.8	-0.1	0.0
	13.9 meters	13.9	18.5	20.3	-1.3	0.1	10.9 meters	18.3	19.9	20.8	0.0	0.1
	Mid Channel 14 meters	13.6	18.3	20.2	-1.8	0.2	Mid Channel 14 meters	16.1	18.3	20.4	-0.3	0.2
Barrier Down	5.2 meters	20.9	21.3	21.8	0.0	0.0	2.6 meters	21.0	21.5	22.3	0.0	0.0
	8.1 meters	19.3	21.1	21.6	-0.2	0.0	5.6 meters	20.9	21.3	21.7	0.0	0.0
	11.5 meters	15.8	19.4	20.6	-0.6	0.2	8.8 meters	18.6	20.8	21.1	-0.2	0.1
	13.9 meters	14.2	17.9	19.8	-0.2	0.3	10.9 meters	17.2	19.7	20.6	-0.4	0.1
	Mid Channel 14 meters	13.5	17.6	19.6	-1.6	0.4	Mid Channel 14 meters	15.6	17.7	19.5	-0.8	0.3
Drain On	5.2 meters	21.1	21.5	21.9	0.0	0.0	2.6 meters	21.0	21.6	22.3	0.0	0.0
	8.1 meters	20.2	21.4	21.7	-0.1	0.1	5.6 meters	21.1	21.6	21.9	0.0	0.0
	11.5 meters	17.5	20.3	21.5	-0.4	0.2	8.8 meters	20.2	21.2	21.7	-0.2	0.0
	13.9 meters	14.6	19.0	20.9	-0.6	0.2	10.9 meters	18.0	20.5	21.7	-0.2	0.1
	Mid Channel 14 meters	14.2	19.1	21.3	-1.3	0.2	Mid Channel 14 meters	16.1	19.0	20.8	-1.1	0.2
Spill	5.2 meters	20.7	21.0	21.4	0.0	0.0	2.6 meters	20.7	21.1	21.7	0.0	0.0
	8.1 meters	19.8	20.9	21.3	-0.3	0.0	5.6 meters	20.8	21.1	21.4	0.0	0.0
	11.5 meters	18.0	19.6	20.8	-0.4	0.1	8.8 meters	19.6	20.7	21.2	-0.4	0.0
	13.9 meters	15.1	18.4	20.3	-0.9	0.2	10.9 meters	18.2	19.9	20.8	-0.3	0.1
	Mid Channel 14 meters	15.2	18.9	20.5	-0.6	0.2	Mid Channel 14 meters	16.6	19.2	20.6	-0.9	0.1
Nighttime lockages	5.2 meters	18.4	20.5	21.1	0.0	0.0	2.6 meters	20.4	20.6	21.2	0.0	0.0
	8.1 meters	18.8	20.4	21.0	-0.2	0.1	5.6 meters	20.4	20.6	21.0	0.0	0.0
	11.5 meters	17.0	19.3	20.1	-0.3	0.2	8.8 meters	19.7	20.3	20.7	-0.2	0.0
	13.9 meters	14.1	18.2	19.7	-0.6	0.3	10.9 meters	18.0	19.5	20.2	-0.2	0.1
	Mid Channel 14 meters	13.0	18.4	20.0	-0.8	0.5	Mid Channel 14 meters	16.0	17.9	19.4	-0.9	0.2

Gray areas where unable to be calculated. DO levels where to equal at these levels to determine an affect. Temerature change didn't produce reliable results to make a conclusion.